

# **Identifying Electronic Properties Relevant to Improving Stability in a-Si:H-Based Cells and Overall Performance in a-Si,Ge:H-Based Cells**

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## **PREFACE**

This Final Technical Progress Report covers the work performed at the University of Oregon for the period 18 April 1994 to 15 January 1998 under NREL Subcontract Number XAN-4-13318-07. The following personnel participated in this research program:

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## EXECUTIVE SUMMARY

The work carried out under NREL Subcontract XAN-4-13318-07 has been focused on the characterization and evaluation of low gap (a-Si,Ge:H) alloy materials and on issues related to overall stability in the mid-gap (a-Si:H) materials. First of all, we characterized a extensive series of Uni-Solar a-Si,Ge:H samples using drive-level capacitance profiling (DLCP) and the analysis of sub-band-gap photocapacitance and photocurrent spectra. We thus identified several bands of deep defect transitions. We had hypothesized that one type of defect band optical transition in these alloys, that did not seem to be present in pure a-Si:H, might indicate a significant population of  $D^+$  states in these nominally intrinsic a-Si,Ge:H samples. We also carried out light induced degradation studies of these alloys which tended to support this conclusion and indicated that charged defect ratios could vary significantly after light soaking. We then examined the properties of very lightly n- and p-type a-Si,Ge:H material which verified that charged defects are indeed responsible for the different observed defect bands in device quality a-Si,Ge:H alloy material. This conclusion undoubtedly will have important consequences for understanding the transport and degradation process in a-Si,Ge:H devices.

Second, we reported results of our measurements on a-Si,Ge:H alloy "cathodic" samples produced at Harvard University. These samples were found to exhibit significantly lower defect densities in the high Ge composition range ( $>50\text{at.}\%$  Ge) than alloy samples produced either by conventional glow discharge or photo-CVD deposition. Moreover, this lower defect density appeared to be entirely consistent with simple defect formation models given the differences observed for other aspects of the electronic structure in these samples: a larger gap energy for a given Ge fraction, a different relative energy position of the defect within the gap, and a smaller Urbach energy. However, our measurements also indicated a much smaller value of  $(\mu\tau)_h$  for these samples than would have been expected given their lower defect densities.

Third, we performed voltage pulse stimulated capacitance transient measurements on a-Si:H/a-Si,Ge:H heterostructure samples to look for carrier trapping states that might be associated with this interface. We found there was a clear signature of trapped hole emission extending over long times associated specifically with the interface itself in concentrations of roughly  $10^{11}\text{cm}^{-2}$ . However, we found that these hole traps did not seem to act as recombination centers for electrons brought into the interface region. Nonetheless, these traps seem to exist in sufficient densities to alter the electric field profiles across such heterojunction structures and, therefore, impact the performance of cells which incorporate such interfaces.

Fourth, we reported our results on several hot-wire a-Si:H samples produced with varying hydrogen levels. These samples were evaluated in both their as-grown state as well as the light degraded state. We found that samples with a H content above  $10\text{at.}\%$  exhibited essentially identical properties to those of conventional glow discharge a-Si:H. However, as the H level was decreased to about  $2\text{at.}\%$  the electronic properties actually *improved*: the degraded defect level was reduced and the Urbach tail was slightly narrower. These changes were accompanied by more than a  $0.1\text{eV}$  decrease in optical gap. Therefore, our studies indicate that hot-wire produced a-Si:H, with H levels between  $2\text{-}5\text{at.}\%$ , should lead to mid-gap devices with superior properties.

Finally, we discussed some results on glow discharge material as well as ECR deposited a-Si:H grown under hydrogen dilution conditions. We confirmed that, in terms of deep defect creation, such films exhibited improved stability compared to conventional glow discharge material: roughly a factor of three lower deep defect densities than those grown using pure silane. Furthermore, the hydrogen diluted samples degraded at a slower rate and saturated at a significantly lower value (by about a factor of five) than pure silane deposited sample. These results agree with reports of increased relative stability of cells employing hydrogen-diluted i-layers. To try to gain some insight into the mechanisms responsible for such differences in stability we also compared Ar and H diluted  $\text{SiH}_4$  grown samples with a sample that was switched periodically between these two types of gas mixtures during growth. While still very preliminary, our studies indicate that film strain may play an important role.